Quality of Rainwater from Rainwater Harvesting System: Variation of Rainwater Quality in Different Environment

By

Awang Bolkiah Bin Awang Su'ut

Dissertation submitted in partial fulfilment of
the requirements for the
Bachelor of Engineering (Hons)
(Civil Engineering)

MAY 2012

Universiti Teknologi PETRONAS
Bandar Seri Iskandar
31750 Tronoh
Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

Quality of Rainwater from Rainwater Harvesting System: Variation of Rainwater Quality in Different Environment

by

Awang Bolkiah Bin Awang Su'ut

A project dissertation submitted to the

Civil Engineering Programme

Universiti Teknologi PETRONAS

In partial fulfillment of the requirement for the

BACHELOR OF ENGINEERING (Hons)

(CIVIL ENGINEERING)

Approved by,

(AP. Dr. Nasiman Sapari)

Assoc. Prof. Dr Nasiman b. Sapari
Lecturer
Civil Engineering Programme
Universiti Teknologi PETRONAS
31750 Tronoh
Perak Darul Ridzuan, MALAYSIA

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

APRIL 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

(AWANG BOLKIAH BIN AWANG SU'UT)

ABSTRACT

The objectives of this research are to determine the quality of harvested rainwater from two different area with different environment, and to design a cut-off system or a "first flush" system in order to divert poor quality of rainwater from a rainwater harvesting system before the rainwater can be use for daily purposes. A rainwater harvesting model were built and installed at two different area; Ipoh, Perak Darul Ridzuan, and Kerteh, Terengganu Darul Iman. Ipoh is known as an urbanized area and the capital city of Perak, while Kerteh is known as an industrialized area with lots of petrochemical plants and crude oil refineries. A total of 7 rain events were managed to be sampled. 4 Parameters were analyzed; pH, Turbidity, Total Suspended Solids (TSS), and conductivity.

For the rainwater samples from Ipoh, the highest pH was recorded at 7.39, and the lowest pH was recorded at 7.15. For turbidity, the highest value was recorded at 3.11 NTU, while the lowest was at 1.88 NTU. For TSS, the highest value was recorded at 9.50 mg/L and the lowest was at 5.65 mg/L. The highest conductivity was recorded at 73 uS/cm while the lowest value was recorded at 25 uS/cm.

For the rainwater samples from Kerteh, the highest pH was recorded at 6.74, while the lowest value was recorded at 6.42. For turbidity, the highest value was 6.37 NTU and the lowest was recorded at 1.08 NTU. The highest TSS value was recorded at 45.1 mg/L, and the lowest was at 5.31 mg/L. For Conductivity, the highest value was recorded at 120 uS/cm, and the lowest value was recorded at 10 uS/cm.

Based on the data analyzed, we found out that a minimum of 1.357mm of rainfall needed to be diverted from the rainwater harvesting system to ensure that the quality of rainwater is in the optimum level. Therefore, a "first flush" tank must be able to divert a total of 1.357mm of rainfall before the rainwater can be stored and use.

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1
INTRODUCTION

1.1 Background of Study

Water is one of the most important resources in this world. It is essential for all living things including human being. We need water for activities ranging from our daily routine such as drinking, cooking, washing, and extend to bigger activities such as industrial and agriculture. As the growth of population increase, global demand of good water quality is increasing. Despite this, the change in climate and pollution caused by industrialization are reducing raw water sources. Therefore, a new ways of getting water has been developed as an alternative of getting new resources of water.

Rainwater Harvesting (RWH) is one of the methods that can be used to solve scarcity. This method utilizes rainwater as its source of water, via direct collection of rainwater from roofs and other purpose built catchments. The practice of RWH system is not something new. Archaeological evidence attests to the capture of rainwater as far as 4000 years ago. This system was utilized because water supply systems were not developing yet. Even though the technology of RWH has changed in time, but its concept remains the same.

In 1998, Malaysia facing the serious water crisis because of the drought from climate changes. The drought spurred government's interest in rainwater harvesting and utilization. On 7th May 1998, the Minister of Housing and Local Government produced a guideline on installation of a Rainwater Collection and Utilization system.

1.2 Problem Statement

1.2.1 Problem Identification

Although studies have shown that the quality of rainwater is better compare to untreated lake or river water, but rainwater to be use as potable water is still debatable. No question that rainwater can still be use as non-potable water such as for toilet flushing. Some studies have reported that roof-harvested rainwater quality is generally acceptable for use as potable water. In contrast, some reports also had shown the existence of pathogenic micro organism in roof water samples. There are many factors contributing to these foundings, for example the location of the RWH. Limited research and epidemiological evidence on rainwater quality might contribute to this misunderstanding of rainwater quality.

Rain is a form of precipitation in which water falls back to earth as a liquid. The water that falls as rain comes mainly from oceans, but also to a lesser extent from lakes and rivers. Heat from the sun causes water to evaporate, that is, to change phase and become a vapour. The water vapour rises and, as it does, reaches a level in the atmosphere where the temperature is cool enough for it to change back into a liquid, a process we know as condensation. Logically, the rainwater produced is in good quality and free from contaminants. But the emission of trace organic compounds, such as Polycyclic Aromatic Hydrocarbon (PAHs) due to a result of the combustion of hydrocarbon-based fuels will mix with the water vapour in the air. Some of this will precipitate out as contaminated rain. PAHs are known to be carcinogenic, the main cause of cancer.

For RWH system, rainwater falling on the roof flows along gutters through down pipes into the tank. House roof may contain animal faeces, mosses and lichens, windblown dust, fallen leaves or even particulates from urban pollution. Also, PAHs can settle at the surface of the runoff, and can be washed off by the rainwater. Roof material may also affect the quality of rainwater and contribute to the existence of iron compound in water, depending on the roof material. These contaminants will affect the quality of the rainwater, making it undrinkable and not suitable for bathing and clothes washing, making the usage of rainwater limited towards only for toilet flushing or lawn watering.

1.2.2 Significant of the project

The analysis of the quality of the harvested rainwater is important in determining the usage of the system itself. If the rainwater is too contaminated, then it can only be used for activities such as toilet flushing. In order to increase the usage of rainwater, not limited only for flushing like the existing system, we need to examine and understand the quality of the rainwater first before developing a better system of RWH. An ideal RWH system would be able to convert rainwater into potable water, which can be use as drinking water, bathing and washing purposes, replacing the traditional water supply system that we utilise today. In order to create this RWH system, we need to identify the contaminants found in rainwater, so that we can propose suitable treatments to remove these contaminants. A simple RWH can only collect the rainwater without treating it first, but by analysing the quality of the harvested rainwater, important treatment system can be installed together with the RWH in order to get a good quality of water.

1.3 Objective of the project

The objective of the project is to:

- Analyse the quality of the harvested rainwater in different environment namely urban and industrial area and identify the main contaminants and pollutants in it.
- Design a suitable cut-off first flush system by determining how much rainwater is needed to flush away all the contaminants before it can be used and consume.

1.4 Scope of study

The scope of study of the project involved the collection of harvested rainwater at two different environments. The first sample collections were done at the urban area of Ipoh, Perak Darul Ridzuan. The second sample collections were done at the industrial area of Kerteh, Terengganu Darul Iman. The rainwater was collected by using a rainwater harvesting model that was constructed prior to normal house roofs.

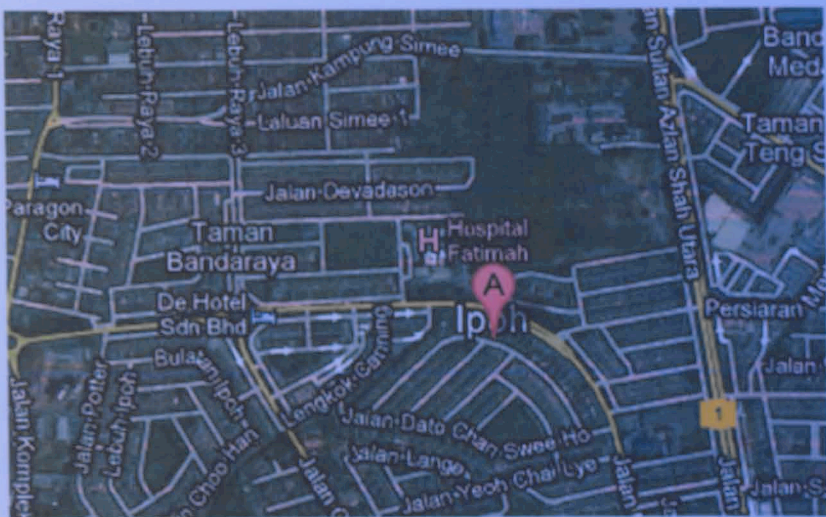

Figure 1.1: Map of Ipoh, Perak Darul Ridzuan

Figure 1.2: Map of Kerteh, Terengganu Darul Iman

The samples of the harvested rainwater were analyzed through laboratory test to determine the quality of the rainwater. 4 parameters were analyzed; pH, Turbidity, Total Suspended Solid and Conductivity. Data obtained through the analysis were recorded. From this data, we can identify the quality of the rainwater harvesting and the minimum volume needed to design the cut-off first flush system for a household rainwater harvesting system.

1.5 Relevancy of the Project

This project is relevant towards civil engineering field as one of the steps in promoting green technology in the construction industries. RWH can be an alternative approach in water resource, rather than the conventional ways of water supply system which is obtained from lake, river or ground. It is cost effective, and can be a solution of water shortage problem.

The analysis of the quality of the rainwater in a way can help in developing the RWH system. Most RWH system in Malaysia nowadays does not have a proper treatment process; therefore the usage of harvested rainwater is very limited. With the data obtained, we can identify the quality of the rainwater, thus providing sufficient data in order for us to propose a proper treatment process that can be installed together with the RWH system.

1.6 Feasibility of the project

The project commenced by collecting materials needed such as books, journals, and technical papers on RWH system. All available method that is relevant towards this project is being taken into consideration and selection is based on the reliability as well as time constraint in getting satisfactory result.

Research was done from time to time as part of getting a better understanding on this issue and to compare our own findings with the available information.

The project was completed within a period of 6 months. The equipments and materials needed to build the Rainwater Harvesting Model can be found on hardware stores. For Laboratory tests, equipments and apparatus needed are available in the Civil Engineering Laboratory. With all the resources provided, this project can be considered as a feasible project within the time frame given.

CHAPTER 2
LITERATURE REVIEW

2.1 Rainwater Harvesting

In recent decades, rainfall has been considered a source of pollution from the moment it is formed in the atmosphere, continuing on the urban impervious surfaces – streets, roads, roofs and yards – where the stormwater run-off is mixed with all kinds of materials and pollutants accumulated during dry periods. A major objective of rainwater management is to assume stormwater as an important resource and not as a nuisance, implementing measures to protect the natural water cycle and ecological systems (Niemczynowicz, 1999).

What is Rainwater Harvesting? RWH is a system which consists in numerous technologies used to collect water from rooftops and yards, and storing it in tanks or reservoirs for later uses, providing water for the purpose of meeting demand by humans and/or human activities. The RWH level varies from household level to large-scale water harvesting projects, and its technologies can be split into two types depending on source of water collected: *in situ* and *ex situ* techniques of RWH (UNEP, 2009).

2.2 Rainwater Harvesting System usage in Urban Areas

Cities are characterized by their extensive impermeable soil with hardly any natural infiltration. Its drainage systems were built to collect the urban flows in order to attenuate the peak flow, avoiding problems of flooding downstream. However, with increased variability and intensity of precipitation, coupled with solid waste pollution typical of cities, stormwater sinks are no longer effective in drainage of surface runoff and fail to provide flood protection. Adding stormwater collecting points within an urban catchment has the potential not only to provide protection against the risk of flooding, but also to allow the storage of freshwater, suitable for other requirements and to meet demand (Mitchell et al, 2007).

2.3 The setback of a Rainwater Harvesting system implementation

The main inconvenience of RWH is associated to the limited supply and uncertainty of rainfall. Rainwater is not a reliable water source; therefore this is a less attractive issue to some governmental agencies tasked with providing water supplies in developing countries, especially those affected by prolonged droughts. Other numerous barriers to the acceptance of systems exist. The most relevant barriers and inconveniences to the uptake of RWH are (Mitchell et al., 2007, Roebuck, 2007, Kahinda et al., 2007, Farahbakhsh et al., 2009):

- Absence of legally binding water quality standards: unwillingness of any Government or regulatory body to take responsibility for setting and monitoring standards;
- Lack of information regarding RWH system costs and maintenance requirements;
- Difficulty in achieving and maintaining reliable level of water quality;
- Lack of public awareness and acceptance;
- Current low cost of public mains water makes investment profit in water efficiency measures unattractive: water companies focus is on reducing consumer costs not on creation of a sustainable water supply system; and, the cost of water is rarely a driver for the end-user but cost of installing a RWH may be seen as significant;
- Storing capacity limits the amount of harvested rainwater;
- Rainwater can be contaminated by all sorts of microbiological and chemical pollutants thus, if not properly treated before usage, may cause serious health risks;
- It is also acknowledged that harvesting excessive amounts of urban stormwater runoff could be detrimental to stream health;

2.4 Potential Use of rainwater

Most water used in homes and industries does not need high quality water – e.g., toilet flushing and gardening. As we can see in Figure 2.1, many of the activities typical of every household do not require potable water (Harmer Kessel, 2009).

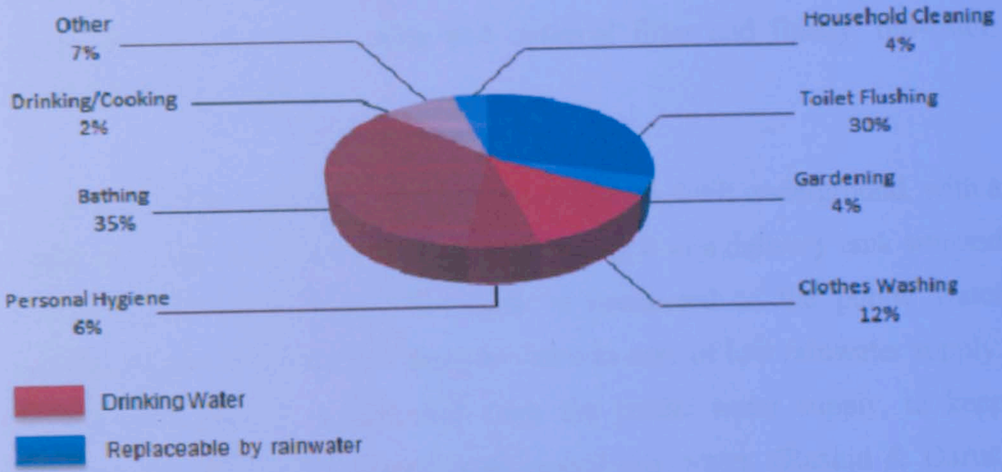

Figure 2.1: Distribution of water consumption in a common dwelling (Source: Harmer Kessel, 2009).

2.5 Example of implementation of rainwater harvesting

2.5.1 Universiti Kebangsaan Malaysia, UKM

In March 2006 the Ninth Malaysia Plan (9MP) was announced to the country. This plan consists of the allocation of the national budget between the years 2006 and 2010 to all economic sectors, in order to overcome Asian financial crisis towards economic and environmental sustainability. (Rashid & Darus, 2009)

Under this initiative, the Universiti Kebangsaan Malaysia (UKM) began the construction of a new building in the Faculty of Science and Technology consisting of two blocks, namely the Administration edifice and the Laboratory edifice. It's in this new complex, financed by the 9MP in about

RM 750 million, that will be installed the pilot project of RHS. (Rashid & Darus, 2009)

Initially, this system was implemented only for the Administration Building, since it is the first one to be constructed. Its rooftop was considered to be the most suitable catchment area and from there, the rainwater is conveyed through the gutters, into the downpipes which are linked to the filtration tank. The filtration tank is where the water collected will be filtered before channelled to the storage tank. The filtration method consists of three phases: natural sand filter, stone and charcoal filter and finally, bio-filter. (Rashid & Darus, 2009)

The storage tank is a solid concrete structure, built underground, with a capacity to store 50 m3 of water before pumping it to a delivery tank situated on the top of the building. This tank is connected to the public water distribution system, which will provide water in case of low rainwater supply. The plumbing system is separated from the public water supply, to keep harvested rainwater from mixing with treated city water. (Rashid & Darus, 2009)

The main goal of this project is to provide the maximum water for toilet flushing and building washing. According to the data available in this paper, the amount of water demand only for toilet flushing in the Administration Block can be covered by the harvested rainwater in the month with the lowest average rainfall (January). (Rashid & Darus, 2009)

At first, the water collected will be applied for toilet flushing and building washing, but eventually could be used for other activities such as washing vehicles and watering plants and gardens. (Rashid & Darus, 2009)

The implementation of this project in the UKM will bring many economic and social benefits. It will provide water for non-potable uses reducing the consumption of drinking water thus helping to reduce the dependence on the public system, and therefore on water bills. Socially, it will be an important step to attract and involve students and practitioners who are interested in this subject, contributing for future research (Rashid & Darus, 2009)

2.5.2 University of North Carolina – The Bell Tower Project

The University of North Carolina (UNC) at the town of Chapel Hill is the oldest public university in the USA and one of the more aware that we live an era of crisis, always looking to create innovative solutions to a complex array of issues using a holistic, sustainable approach. (Efland et al., 2008)

In the year 2000, an investment was made in the university campus of around 2 billion U.S. Dollars (USD) (1.5 billion €) for various program improvements, including the construction of the Bell Tower Project (BT), one of the greatest buildings ever completed on campus. This project involved an investment of 231.5 million USD (170 million €) and consists of a multi-purpose complex whose main feature is its innovative water grid, which is being incorporated into the design as part of a pilot project for testing and optimization. (Efland et al., 2008)

The construction of this complex aims, in addition to the educational services offered, to accomplish the fulfilment of several key strategies including reducing water consumption of the public network, and storm water management, by maintaining or improving water quality, peak discharge attenuation and total volume reduction. (Efland et al., 2008)

It is located immediately upstream of the confluence of two small streams of 10 and is 25 hectares in size. The existing buildings of the BT occupy much of the perimeter of the 10 hectare sub-watershed and a 16,350 m2 asphalt parking lot is situated in the centre of the watershed. The Genome Science Laboratory Building (GSB) and the parking deck, which are the major structures of this development, will be connected by a new central park, a large green area that replaced the existing parking lot. (Efland et al., 2008)

Below this park lies the stormwater management facilities, composed by a "1,365 m3 concrete stormwater detention structure and a 1,325 m3 stone-filled cistern for storage and reuse of harvested roof water." All new and existing stormwater surface pipe and drainage systems are connected to the underground concrete detention system. (Efland et al., 2008)

The water that falls on building rooftops will be captured and reused as a water supply source for irrigation and toilet flushing, promoting the concept of non-potable water (NPW) system. This system also incorporates an automatic reclaimed water makeup system to provide a reliable secondary source of water, when the city experiences severe droughts. The entire stormwater management facility has the ability to treat approximately 2,690 m3 of stormwater. (Efland et al., 2008)

According to this article, upon completion of this project, the NPW systems will reduce UNC"s demand on Orange Water and Sewer Authority (OWASA) potable water "by an average of 3,785 m3 per day, or about 10% of the average daily demand of the entire OWASA system. This volume reduction is expected to increase to 5,678 m3 per day by the year 2028. (Efland et al., 2008)

2.6 Quality of the harvested rainwater

2.6.1 Pathogenic Microorganism in harvested rainwater

Rainwater harvesting from rooftops is subject to contain a wide variety of microorganisms from various sources. Although many are considered safe and not likely to cause illness, their presence indicates that disease-causing organisms (pathogens) could be in the stored rainwater. Therefore, water quality and safety will be ensured by the minimization or exclusion of their presence (enHealth Council, 2004).

The most common indicators of faecal contamination generally used for assessing the microbial quality of water are *Escherichia coli* (E. coli) and *faecal coliforms* (or Thermotolerant coliforms). However, an increasing number of microorganisms are being added to the current US Environmental Protection Agency (USEPA) microbiological guidelines for water that is going to be ingested in some manner by the consumer. Some pathogenic and opportunistic organisms, such as *Salmonella spp.*, *Pseudomonas aeruginosa*, *Legionella spp.*, *Campylobacter* spp. and *Cryptosporidium* (protozoan pathogens) are often present in harvested rainwater (Lye, 2002). These organisms are likely to cause possible health problems to its consumers and therefore none of them is allowed (zero CFU per 100 ml) in high quality drinking water sources (Lye, 2002). Thus serious doubts were raised about whether traditional indicators will be sufficient to accurately assess the state of water safety.

Microbial quality/contamination of harvested rainwater from roofs depends on several factors (EnHealth Council, 2004 and Meera & Ahammed, 2006):

- faecal material (droppings) deposited by birds, lizards, rats and other climbing animals;
- dead animals and insects, either in the roof or gutters, or in the tank itself – can lead to direct faecal contamination and has a certain impact on the water taste and odour;
- soil and leaf litter accumulated in gutters, especially if kept damp for long periods due to poor drainage;
- type of roof – microbial quality of water collected from metallic roofs is usually better than that from other types of roofs;
- Periods between precipitation events – contamination increases with longer dry periods between rainfall episodes due to greater deposition occurrence on roofs.

- Weather patterns and environmental conditions: wind speed/direction, temperature and rainfall intensity – can significantly influence the bacterial load of roof run-off.

The majority of storage tanks are installed above ground. Yet, underground tanks will not cease to exist. These require higher constructive considerations, since if they aren't fully sealed and protected against run-off, microorganisms in the soil associated with human and animal faeces may also contaminate stored rainwater (enHealth Council, 2004). Additionally, rainwater tanks serve as an excellent site for mosquito breeding. Besides the discomfort and nuisance they cause, certain types of mosquitoes can be vectors of viruses and diseases, such as malaria and the dengue virus, especially in 3rd world countries located in tropical and subtropical areas, where water scarcity is a capital problem. To avoid or minimize this situation, it is recommended that all tanks should have devices to prevent mosquito proliferation (enHealth Council, 2004).

There are many surveys about the influence of the storage period and location of rainwater cisterns on the microbiological quality of water. It is considered that relatively clean water entering the tank will generally improve in quality if allowed to sit inside for some time. However, it is possible that certain bacterial strains are likely to proliferate during storage and that levels remained constant during long term storage. It is assumed that these contradictory results are linked to the availability of nutrients and environmental conditions, suitable for bacterial proliferation in storage cisterns. Therefore, physical location of the tanks is of utmost importance (Meera & Ahammed, 2006). They should be sited in a shady, dark spot to prevent algae growth and keep water cool (The Schumacher Centre for Technology & Development, 2008).

Numerous studies from different parts of the world (Lye, 2002; EnHealth Council, 2004; Meera & Ahammed, 2006; Sazakli et al., 2007) reported that the microbiological quality of rainwater is often suspect and does not meet microbial drinking-water quality standards. Consumption of untreated stormwater is likely to cause some health related problems, yet more studies are necessary to assess the real microbial risk of rainwater to human beings.

Despite these revealed conclusions, Meera & Ahammed (2006) emphasised that "collected rainwater still represents the best option in many situations in terms of microbiological quality", sometimes even better than that of other sources of drinking water such as shallow groundwater.

A rooftop RWH system is essentially composed of a catchment surface (roof), a conveyance system (gutters or pipes) and a storage structure (a cistern or a tank). During this process there is a potential for chemical, physical and microbiological contamination, in all three stages. Despite roofs being higher than the ground, it doesn't mean they are free from dirt, dust, faeces from birds and small animals and other debris, such as leaves and twigs. Thus, falling rainwater not only dissolves air pollutants, as when it falls on the roof, but it also dissolves contaminants from the roof material, collects dirt and then flows into storage. Changes may also occur during storage, depending on its location, water depth and the material used (Meera & Ahammed, 2006).

In short, there are several factors that influence the water quality of roof runoff (Lye, 2009):

- Roof material – chemical characteristics, roughness, surface coating and age;
- Construction methods of the roof – size, exposure, inclination;
- Local weather and environmental conditions – season, antecedent dry periods;
- Precipitation events – intensity, wind, duration;
- Chemical properties of pollutants – vapour pressure, solubility in water;

- Location of the catchment surface – proximity to pollution sources: industrial areas, agricultural areas, heavy traffic;

2.6.2 Roof Material

The type of roof material and its periodic cleaning will highly affect the quality of rooftop RWH.

According to numerous studies (EnHealth Council, 2004; Meera & Ahammed, 2006; Hamdan, 2009; Despins et al., 2009) nearly all water quality parameters – turbidity, Total Organic Carbon, hardness, colour, pH, organic matter, concentration of heavy metals, etc – were considered to vary significantly based on the type of rooftop material.

Roofs can be fabricated from a diversity of materials such as concrete, bitumen, asbestos/fibrocement, metal, terracotta and clay tiles, polycarbonate or fibreglass sheeting (EnHealth Council, 2004; Hamdan, 2009).

Differences in roofing material affect turbidity, hardness and colour of harvested rainwater. Wide variations are seen in the concentration of most constituents such as major ions, nutrients, pesticides and heavy metals. According to Zobrist et al. (2000), in a typical rain event, runoff from a tile roof presented high concentrations of most constituents in the first minutes or first tenths mm of runoff depth, while runoff from a gravel roof exhibited a different behaviour, as there was a significant retention of rainwater in the gravel layer.

Studies by Wallinder et al. (2000) and Chang et al. (2004), suggested that variations depended not only on roof material, but also on characteristics of precipitation, orientation and slope of roof, air quality of the region, weather patterns, etc. Dust derived from calcium rich-soils is susceptible to settle in rooftops, consisting in a source of calcium and magnesium in the form of carbonates. Also, acidic ions like nitrates and sulphates are considered to be transported by deposition.

Another important parameter for this subject is the pH value of the harvested rainwater. In theory, pH of rainwater varies between 4.5 and 6.5 but usually increases slightly as soon as it falls on the roof and during tank storage. This chemical phenomenon is of great relevance, once it is a key factor in chemical precipitation of pollutants in stormwater runoff. As it runs on certain types of roofs, like fibrous cement, rainwater tends to become more alkaline which is a favourable condition for precipitation of heavy metals compounds (Zobrist et al., 2000; Hamdan, 2009).

Heavy metals are of singular importance in RWH "due to their toxicity, ubiquitousness, and the fact that metals cannot be chemically transformed or destroyed", by simple treatment processes (Davis et al., 2001). Several attempts have been made over the years to determine the influence of atmospheric deposition, especially in the vicinity of industrial areas, and roofing materials on heavy metal contamination of rooftop runoff. Roofs can act as a source of heavy metals through leaching and disintegration of its building materials over the years. Among the many possible types of materials, metals surfaces in direct contact with falling rainwater, besides being subjected to atmospheric corrosion, will dominate the runoff pollution pattern, especially for lead, zinc and copper (Zobrist et al., 2000; Davis et al., 2001; Chang et al., 2004; Eletta & Oyeyipo, 2008).

The presence of lead in harvested rainwater is the most common since lead can stem from several types of roofs, including polyester, slate, galvanized iron and asphalt shingle roof. Lead fittings have also been suggested as potential sources of contamination of harvested rainwater, mainly in poorly maintained roofs and gutters (Zobrist et al., 2000; Wallinder et al., 2000; Metre & Mahler, 2003). Therefore lead fittings are not recommended. Water quality should be monitored for heavy metals in order to avoid major hazards to human health, especially if the harvested rainwater is to be used for drinking purposes or food preparation.

2.6.3 Tank Material

The design of tanks, the materials used and its location are the most influential issues in obtaining water with good or poor quality.

Tank design solutions include techniques to minimize re-suspension of sediments, such as the installation of a wave absorber mechanism at the tank water inlet in order to reduce water turbulence, and a specialized service for storage tank maintenance. Most storage reservoirs should be equipped with manholes to allow access for cleaning (Lye, 2009).

A study by Han & Mun (2008) revealed that the quality of stored water delivered to the end users will not only determine its final use but will also affect its acceptance by the general public, as a suitable alternative of potable water. They suggested that higher efficiency in particle removal can be obtained by having a considerable distance between inlet and outlet. It is also recommended that tanks should be designed to maintain a minimum of 3 m water depth and to withdraw water from the near-surface by using a floating suction device.

Rainwater reservoirs can be designed from several suitable materials including plastic, concrete, fibreglass and galvanized steel (enHealth Council, 2004). Studies by Zhu et al. (2004) and Despins et al. (2009) reported the effect of storage material on some quality parameters such as taste, turbidity, colour and pH, being this variable the most sensitive to the type of material. Rainwater stored in concrete tanks tends to be more basic, and this could be attributed to the presumable leaching of calcium carbonate from the cistern walls. Rainwater stored in non-concrete tanks is likely to be slightly acidic; however it is unlikely to have a direct health impact on humans. New rainwater cisterns may also provide specific tastes and odours to the harvested water. Concrete reservoirs can release excess lime, inflicting a bitter taste to water. Galvanized tanks can impart a metallic taste when first filled, due to leaching of excess zinc (Despins et al., 2009).

2.6.4 Industrial emissions

The biggest urban and industrial areas are likely to be more air polluted. Thus, there is a greater probability of rainwater becoming contaminated as it falls in these surroundings, by airborne pollutants such as particulate matter and heavy metals. In these localities, rainwater collection for human consumption has attracted most concern since long-term contamination by heavy metals is known to cause numerous biological disorders (Lye, 2009).

Polycyclic aromatic hydrocarbons (PAHs) are a special group of atmospheric contaminants included in the persistent toxic substances (PTS) and also in the volatile organic compounds (VOCs) groups. PAHs are present in the atmosphere and its origin can be due to anthropogenic and/or biogenic activities. Their specific characteristics, high volatility, mutagenic and/or carcinogenic power, easily transportable for long distances with the wind undergoing photodecomposition processes, which imply reactions with solar light, NOx and O3, make them important contaminants despite of the fact that they are present at very low concentrations. These characteristics make some of the PAHs to be listed by the Environmental Protection Agency (EPA) as priority pollutants with negative environmental impact due to their toxicity and they can affect very negatively the living being due to their carcinogenic/mutagenic character. (Mastral et al., 2003)

PAHs can have their origin in anthropogenic and in biogenic sources but most of the atmospheric PAHs are generated and emitted in the combustion processes of fossil and nonfossil fuels (Mastral et al., 2000). PAHs origin is associated with anthropogenic sources such as engine exhausts (Marr et al., 1999), industrial processes (Kirton et al., 1990), natural gas (Rogge et al., 1993), domestic heating system (Oamh et al., 1999), incinerators (Lee et al., 1999), smoke (Zimmermann et al., 1999) and natural sources such as volcanic eruptions and forest fires. It is erroneous to think that PAH emissions in energy generation are only due to unburned material emissions from fossil fuel combustion processes. PAHs can also be emitted from traffic and energy generation, as consequence of pyrosynthetic reactions promoted by a lack of oxygen during the fuel combustion (Mastral et al., 1999), which leads to radical interaction and condensation. The lack of oxygen makes that, in a similar waterfall and very fast process, from small radicals' interaction, high molecular PAHs can be generated and emitted. Due to the PAHs high volatility, PAHs from energy generation can be released both supported onto the particulate matter (PM) and/or in the gas phase (Mastral et al., 2000; Mastral et al., 2001].

Several studies report that the highest levels of PAHs in urban runoff are usually found in the vicinity of industrial areas or intense urban traffic. Moreover, some of them alert for the fact that roof characteristics also seem to affect the level of trace organics in roof runoff. (Zobrist et al., 2000; Moilleron et al., 2002; Polkowska et al., 2002).

CHAPTER 3
METHODOLOGY

3.1 Project Activities

The overall project activities involve for this case study can be divided into 4 different stages:

i. Building a Rainwater Harvesting Model
ii. Samples collection
iii. Laboratory test on samples
iv. Data measurement from the laboratory test
v. Data Analysis (refer to Chapter 4: Result and Discussion)
vi. Reports on findings

3.2.1 Building a Rainwater Harvesting Model

In order to collect rainwater and simulate the process of a RWH system, a Rainwater Harvesting Model will be built. This model is almost identical with a typical RWH system, which consist of two parts, the upper part, and the bottom part. The upper part were consists of a roof, a PVC gutter, piping system, and storage bottles, while the bottom part acts as the roof leg. The model works by capturing the rainwater that fells on the roof and will flow towards the gutter. For this project, a clay tile roofs were chosen for the roofing system because most of houses in Malaysia used them. A PVC gutter was installed to collect the rainwater from the roof. Then, a PVC pipe was connected at the end of the gutter to allow the rainwater flows towards the storage bottles. There are a total of 6 storage bottle that are placed in the system, and the rainwater will flow towards each bottle in sequences. The storage bottle is consists of a bottle cap that is cut according to the T junction diameter and act as a piping valve. A table tennis ball was used as a closing valve when the rainwater fills the storage bottle and diverted the rainwater towards the next bottle. The rainwater will fill the first bottle, and after the first bottle is full, the rainwater will be collected on the second bottle, and it goes on until the last storage bottle. The samples collected in each bottle, including the first flush storage bottle will be tested in the laboratory. Figure 3.1, 3.2, 3.3, 3.4, 3.5 and 3.6 below shows the design of the Rainwater Harvesting Model.

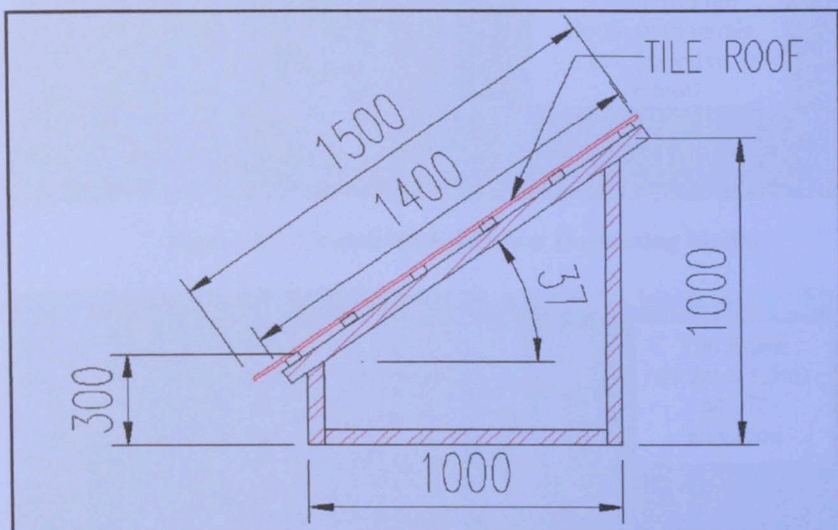

Figure 3.1: Initial design of Rainwater Harvesting Model with dimensions (Side View)

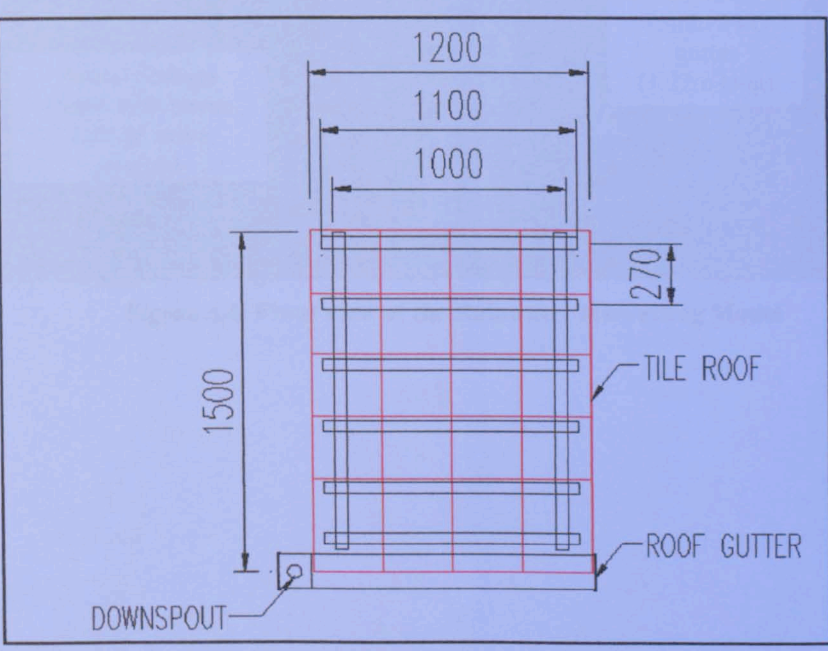

Figure 3.2: Initial design of Rainwater Harvesting Model with dimensions (Plan View)

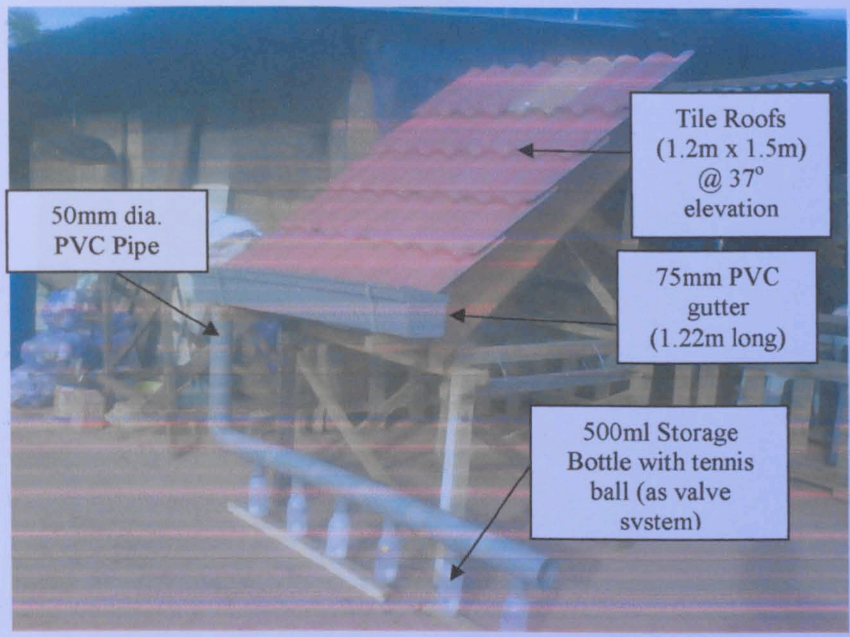

Figure 3.3: Completed Rainwater Harvesting Model

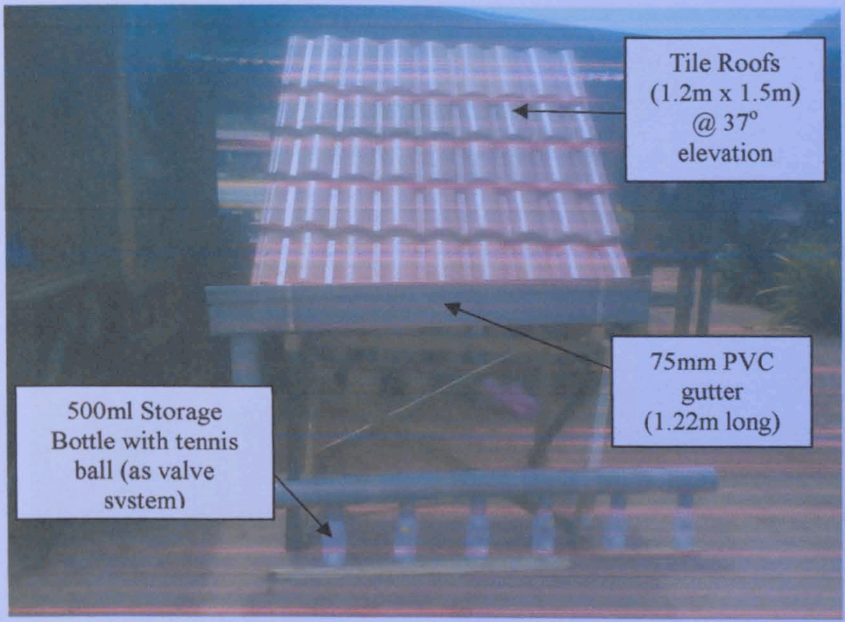

Figure 3.4: Front view of the Rainwater Harvesting Model

Figure 3.5: Upper part of the Rainwater Harvesting Model

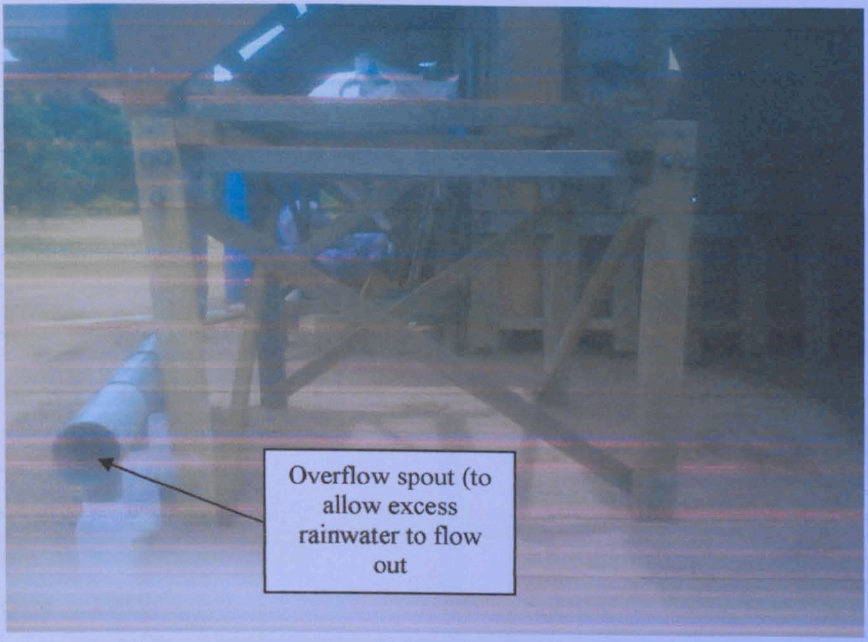

Figure 3.6: Bottom part of the Rainwater Harvesting Model

3.2.2 Samples collections

The samples of rainwater were collected from all the storage bottles from the Rainwater Harvesting Model. The first samples collections were done at the area of Ipoh, Perak Darul Ridzuan, Malaysia. Ipoh is known as an urbanised area and the capital city for Perak state. The second samples collections were done at the area of Kerteh, Terengganu Darul Iman, Malaysia. Kerteh is the base of operations for PETRONAS in Terengganu, overseeing the oil platform operations off the state's coast as well as petrochemicals production and crude oil refining. Therefore, there are a lot of industrial plants and refineries at the area. Each rainfall events and number of preceding dry days were recorded and rainwater samples were sent at Universiti Teknologi PETRONAS (UTP) for further analysis. Table 3.1 below summarized the activity of samples collections at Ipoh, Perak, and Kerteh, Terengganu.

Table 3. 1: Description of rainfall event at Ipoh, Perak and Kerteh, Terengganu

Location	Date	No. Of preceding dry days	Description
Ipoh, Perak	17 Oct 2011	1	Rainwater managed to fill all bottles.
	24 Oct 2011	1	Rainwater managed to fill all bottles.
	2 Nov 2011	1	Rainwater managed to fill all bottles.
	8 Nov 2011	1	Rainwater managed to fill all bottles.
Kerteh, Terengganu	1 April 2012	14	Rainwater managed to fill 4 bottles.
	9 April 2012	8	Rainwater managed to fill all bottles.
	15 April 2012	8	Rainwater managed to fill all bottles

3.2.3 Data measurement from the laboratory test

A laboratory tests were conducted in order to examine the quality of the rainwater harvested. The laboratory tests were done at the Environment Laboratory located at Universiti Teknologi PETRONAS. The parameters to be analyzed included:

- pH measurement
- Turbidity
- Total Suspended Solid (TSS)
- Conductivity

Table 3.2 and 3.3 below shows the summary of analytical method of each parameters and preservation method for rainwater samples respectively.

Table 3. 2: Summary of Analytical methods

Parameter	Meter/Method type	Sources
pH	Sension-2 pH meter	*Standard Methods (1998)*
Turbidity	Turbidity Meter	*Standard Methods (1998)*
Conductivity	Myran L Conductivity Meter	*Standard Methods (1998)*
TSS	Filtration	*Standard Methods (1998)*

Table 3. 3: Sample preservation and storage

Parameter	Preservation	Maximum holding time
pH	None Required	Analyzed immediately
Turbidity	Store at 4°C	48 hours
Conductivity	Store at 4°C	28 days
TSS	Store at 4°C	7 days
PAH	Store at 4°C	7 days

For the first samples collections at Ipoh, there were four parameters analyzed; pH, turbidity, Conductivity and Total Suspended Solids (TSS). There were a total of 4 samples collected, each volume at 1 litre since the storage bottles for the first samples collections were 1 litre each. For the second samples collections at Kerteh, there were a total of 6 samples collected, each volume at 500ml. The volume of the storage bottles were reduced in order to obtained more accurate data. The results from the laboratory tests will be further discuss in Chapter 4.

Table 3.4 below shows the list of tools and material which have been used for the construction of Rainwater Harvesting Model.

Table 3. 4: List of Tools and material used for the construction of Rainwater Harvesting Model

Tools/Material	**Quantity**
1 x 2 wood	15.2 m (~50 ft)
2 x 2 wood	9.4 m (~31 ft)
2 x 3 wood	3.2 m (~10 ft)
3 in. Bolts and nuts	6 pieces
6 in. Bolts and nuts	20 pieces
nails	20 pieces
3 in. plywood	2 m (~7 ft)
PVC pipe	3.7 m (~12 ft)
75 mm PVC gutter	1.22 m long
Gutter downspout head	1
Gutter end cap	2
Pipe elbow	1
Pipe Tee	6
500ml Storage bottles	6
Bottle cap and Tennis ball (for valve system)	6
Manual Saw	1
Automated circular saw	1
Drill machine with drill bits	1
Chisel	1
hammer	1

3.3 Gantt Chart and key milestone for Final Year Project 1

No.	Details\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Selection of projects topic	●													
2	Research on the topic: Rainwater Harvesting for domestic use		■	■	■	■									
3	Consultation with the supervisor	■	■	■	■	■	■	■	■	■	■	■	■	■	■
4	Research for journal or thesis on the respective topic			■	■	■	■								
5	Literature Review/summary for the journal or thesis				■	■	■								
6	Extended Proposal Report					■	■								
7	Submission of Extended Proposal						●								
8	Preparation for Viva presentation							■	■						
9	Viva Presentation/Proposal defence									●					
10	Project works continue										■	■	■		
11	Submit Interim draft report													●	
12	Submit Interim report														●

● Suggested Milestone

■ Process

3.4 Gantt Chart and Key Milestone for Final year Project 2

No.	Details\Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work Continues	■	■	■	■	■	■	■								
2	Submission of Progress report										●					
3	Project Work Continues								■	■	■	■	■			
4	Pre-EDX											●				
5	Submission of Draft Report												●			
6	Submission of Dissertation (soft bound)													●		
7	Submission of Technical Paper													●		
8	Oral Presentation														●	
9	Submission of Project Disertation (Hard Bound)															●

● Suggested Milestone

■ Process

CHAPTER 4

RESULT AND DISCUSSION

4.1 Result and Discussion

The results and Data analysis of the first samples collections from Ipoh has been conducted respectively at 17th October, 24th October, 2nd November and 8th November 2011. For the second samples collections from Kerteh, the collection was done respectively at 1st April, 9th April and 15th April 2012. The experiment that has been conducted included the pH measurement test, Turbidity, Conductivity, and Total Suspended Solids (TSS) test. Each parameter was plotted against rainfall (mm) in order to know how much rainwater was needed to flush away all the contaminants from the roof. The formula to obtain the rainfall unit is shown below:

$$Rainfall, mm = \frac{Volume\ of\ rainwater\ in\ storage, m^3}{Roof\ Catchment\ Area, m^2} \times 1000$$

Where,

$$Roof\ Catchment\ Area, m^2 = length, m \times width, m \times \sin\theta\ of\ roof$$

For the first samples collections at Ipoh, Perak, the dimensions of the roof is 2.2m x 1.7m, and was elevated at 35 degree. The volume for each storage bottle is 1 litre. Therefore,

$$Roof\ Catchment\ Area, m^2 = 2.2m \times 1.7m \times \sin 35^o = 2.15m^2$$

$$Rainfall, m = \frac{0.001\ m^3}{2.15\ m^2} = 4.65 \times 10^{-4}\ m = 0.465\ mm$$

From the calculation above, we can conclude that each storage bottles can capture 0.465mm of rainwater from the catchment roof.

For the second samples collections at Kerteh, Terengganu, the dimensions of the roof is 1.2m x 1.5m, and was elevated at 37 degree. The volume for each storage bottle is 500 ml. Therefore,

$$Roof\ Catchment\ Area, m^2 = 1.2m\ \times\ 1.5m\ \times \sin 37^o = 1.08\ m^2$$

$$Rainfall, m = \frac{0.0005\ m^3}{1.08\ m^2} = 4.63 \times 10^{-4}\ m = 0.463\ mm$$

From the calculation above, we can conclude that each storage bottles can capture 0.463mm of rainwater from the catchment roof.

4.1.1 pH measurement analysis

Figure 4.1 below shows the pH results of the harvested rainwater at the area of Ipoh, Perak Darul Ridzuan. We can see that the pH value for all rain events increased slightly for every millimetre of rainfall. The lowest recorded pH value was 7.15, while the highest recorded pH was 7.39. According to the Interim National Water Quality Standards for Malaysia, the pH value for a Class 1 water ranges from 6.5 to 8.5. These shows that the pH values of the rainwater harvested at Ipoh, Perak are optimum. The scattered reading may be influenced by several factors, such as the material of the RWH model or due to other impurities substance that settles on the roof of the model.

Figure 4.2 below shows the pH results of the harvested rainwater at the area of Kerteh, Terengganu. We can see that the pH value of the harvested rainwater is slightly different for every milimeter of rainwater. The minimum pH was recorded at 6.42, while the maximum pH was recorded at 6.74. As discussed, the pH value of a class I water is between 6.5 and 8.5. Therefore, we can conclude that the rainwater harvested at the area of Kerteh falls under Class II, according to the Interim National Water Quality Standards for

Malaysia. Therefore, a treatment is required for the harvested rainwater. Figure 4.3 shows the median graph of pH value from both rainfall at Ipoh and Kerteh. The pH value of rainfall from Ipoh is much higher than of Kerteh.

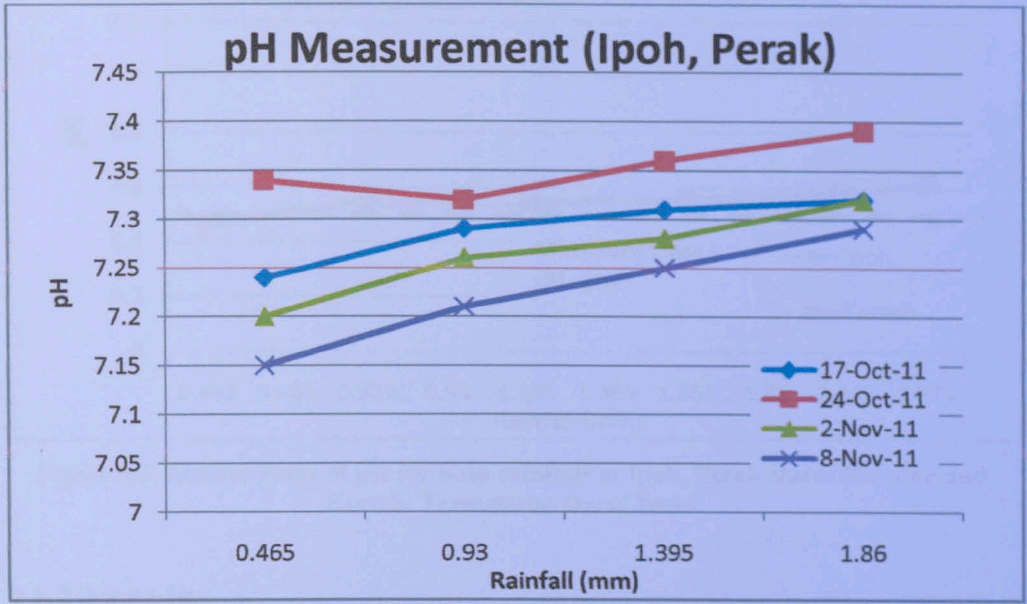

Figure 4.1: pH Measurement for rainwater harvested at Ipoh, Perak

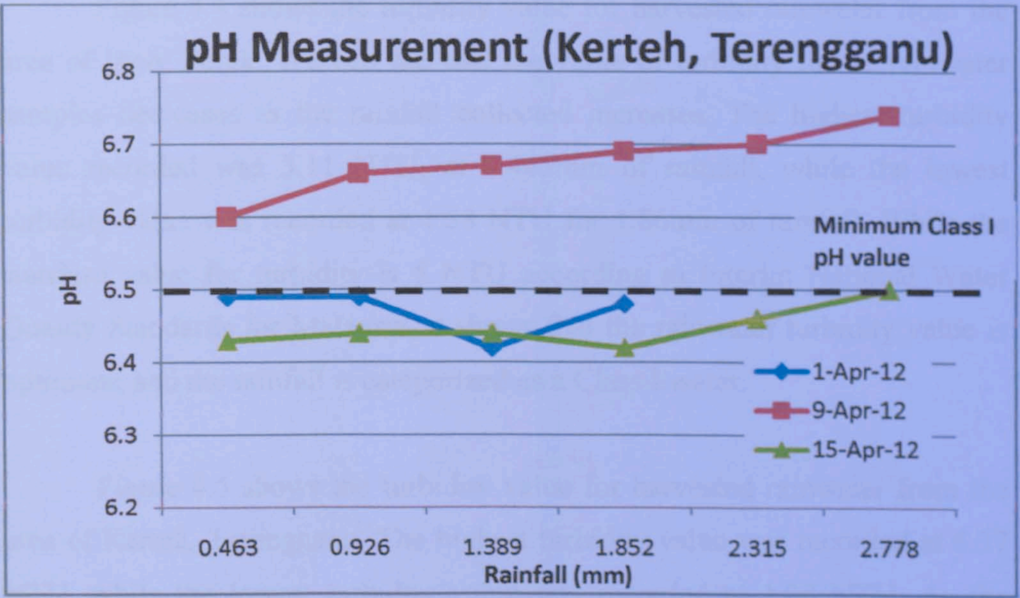

Figure 4.2: pH Measurement for rainwater harvested at Kerteh, Terengganu

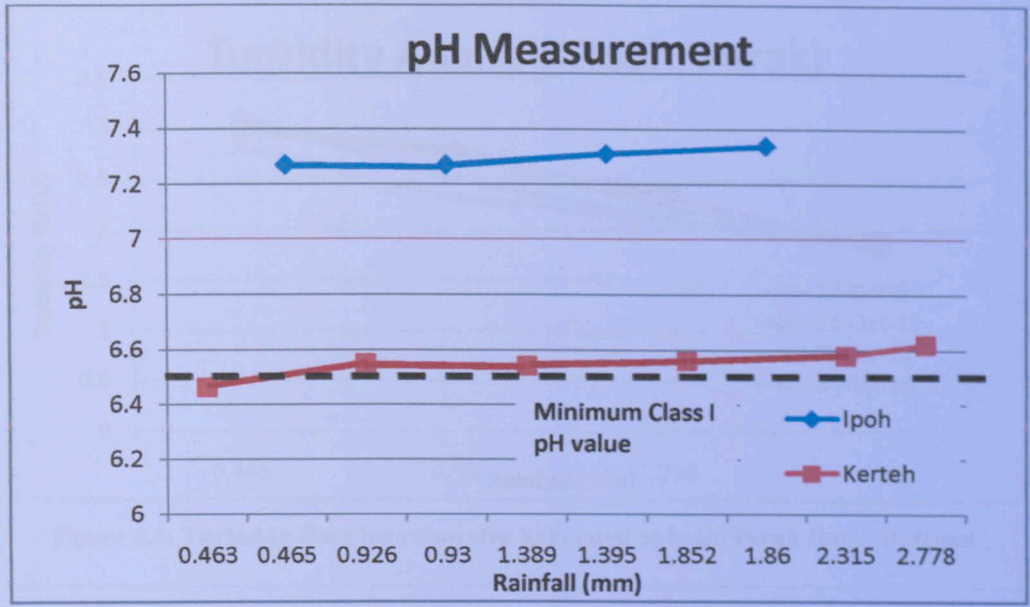

Figure 4.3: Median value of pH for both rainfalls at Ipoh, Perak Darul Ridzuan and Kerteh, Terengganu Darul Iman

4.1.2 Turbidity

Figure 4.4 shows the turbidity value for harvested rainwater from the area of Ipoh, Perak. We can see that the value of turbidity in the rainwater samples decreases as the rainfall collected increases. The highest turbidity value recorded was 3.11 NTU, at 0.465mm of rainfall, while the lowest turbidity value was recorded at 1.88 NTU for 1.86mm of rainfall. While the standard value for turbidity is 5 NTU according to Interim National Water Quality Standards for Malaysia, it shows that the rainwater turbidity value is optimum, and the rainfall is categorized as a Class I water.

Figure 4.5 shows the turbidity value for harvested rainwater from the area of Kerteh, Terengganu. The highest turbidity value was recorded at 6.37 NTU, while the lowest turbidity value was recorded at 1.08 NTU. As the minimum value of turbidity for a Class I water is 5 NTU, we can conclude that based on the graph, 0.971mm of rainwater was needed for the turbidity to reach its optimum level. Figure 4.6 shows the median value of turbidity for both rainfalls from Ipoh, Perak and Kerteh, Terengganu. The turbidity value of rainwater from Kerteh was higher than that of Ipoh.

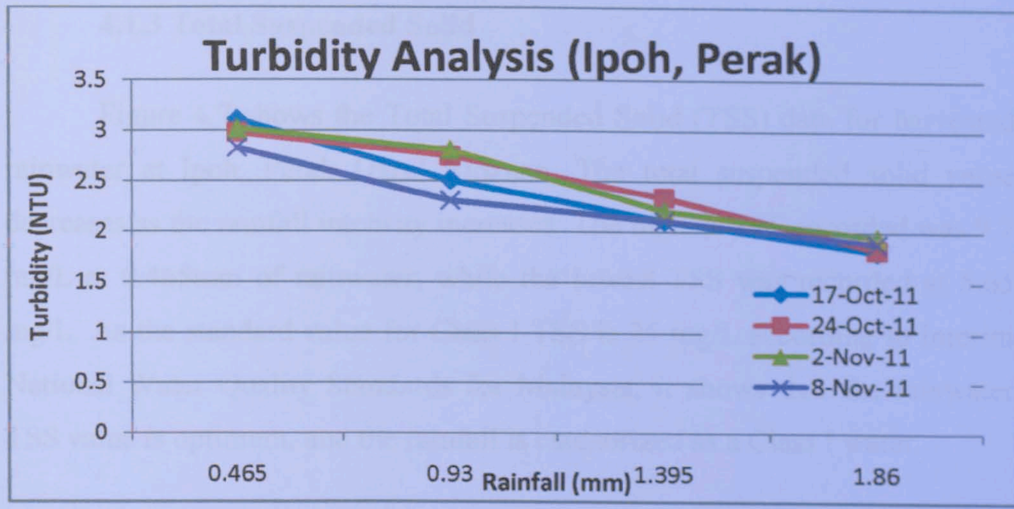

Figure 4.4: Turbidity Data for rainwater harvested at Ipoh, Perak Darul Ridzuan

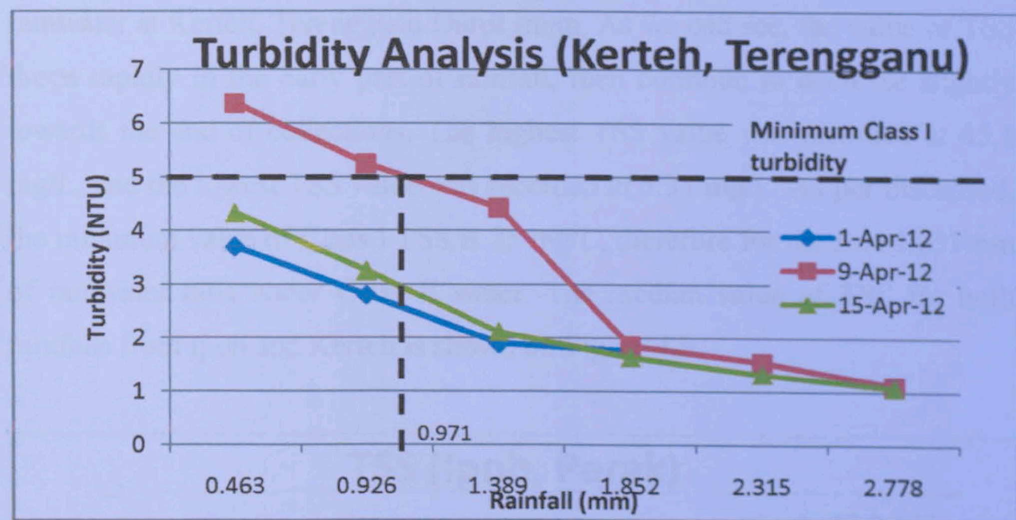

Figure 4.5: Turbidity Data for rainwater harvested at Kerteh, Terengganu

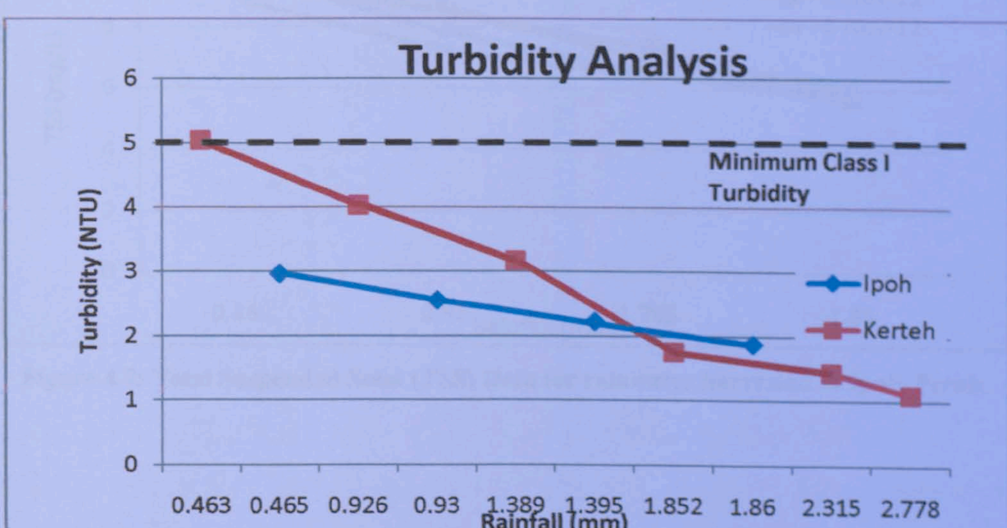

Figure 4.6: Median value of Turbidity for both rainfalls at Ipoh, Perak Darul Ridzuan and Kerteh, Terengganu Darul Iman

4.1.3 Total Suspended Solid

Figure 4.7 shows the Total Suspended Solid (TSS) data for harvested rainwater at Ipoh, Perak Darul Ridzuan. The total suspended solid value decreases as the rainfall intensity increases. The highest TSS recorded was 9.7 mg/L at 0.465mm of rainwater, while the lowest TSS was recorded at 5.65 mg/L. As the standard value for Class I TSS is 25 mg/L according to Interim National Water Quality Standards for Malaysia, it shows that the rainwater TSS value is optimum, and the rainfall is categorized as a Class I water.

Figure 4.8 shows the Total Suspended Solid (TSS) data for harvested rainwater at Kerteh, Terengganu Darul Iman. As we can see, the value of TSS drops rapidly in the early part of rainfall, then continue to decrease slightly towards the end of collections. The highest TSS value was recorded at 45.1 mg/L, and the lowest TSS value was recorded at 5.31 mg/L. As per discussed, the minimum value of Class I TSS is 25 mg/L, therefore for the first 1.357mm of rainwater falls under Class II water. The median value of TSS for both rainfalls from Ipoh and Kerteh is shown on Figure 4.9.

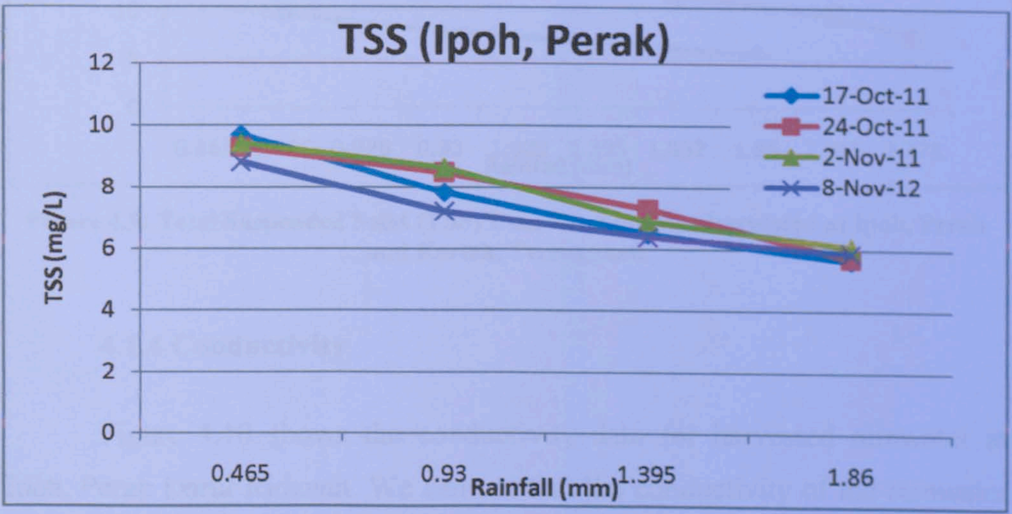

Figure 4.7: Total Suspended Solid (TSS) Data for rainwater harvested at Ipoh, Perak

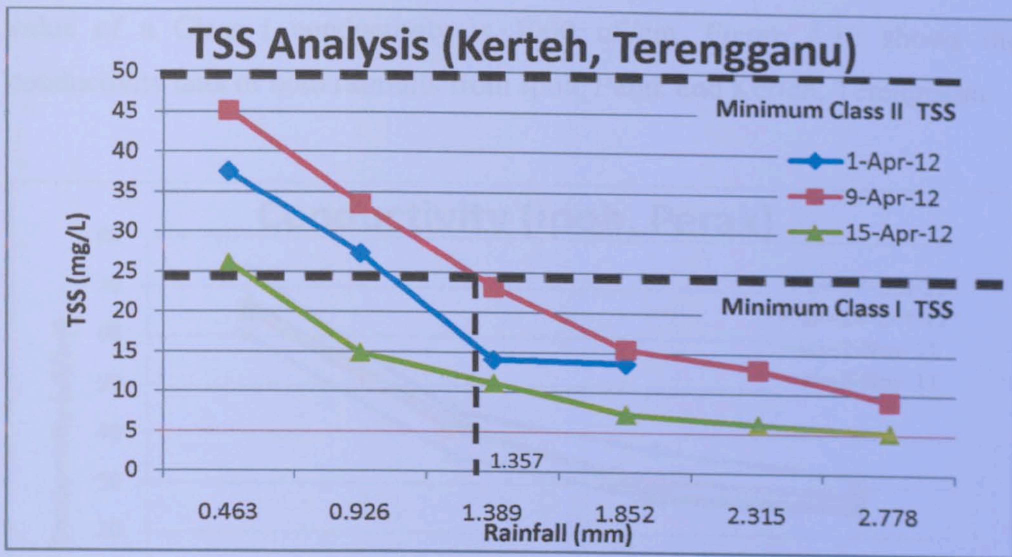

Figure 4.8: Total Suspended Solid (TSS) Data for rainwater harvested at Kerteh, Terengganu

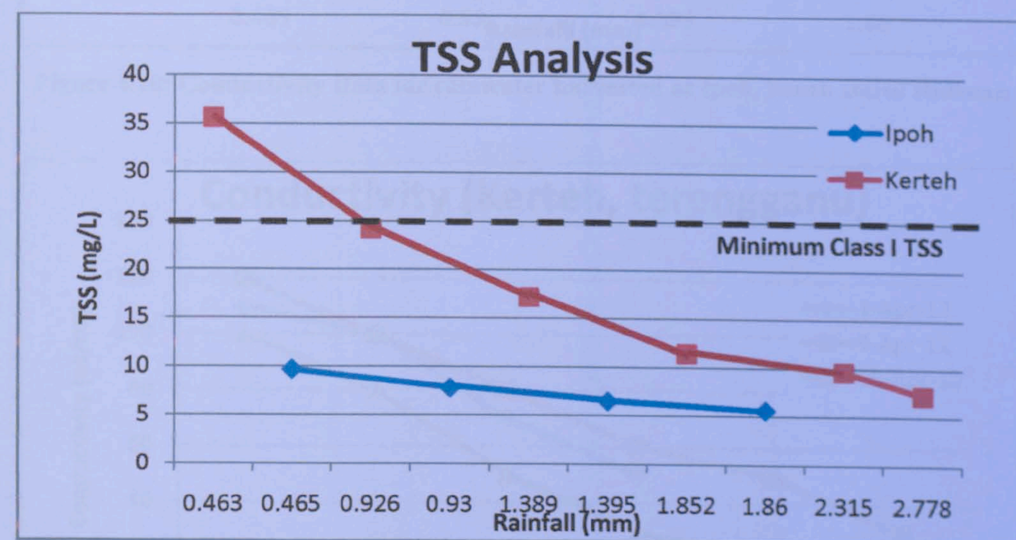

Figure 4.9: Total Suspended Solid (TSS) Data for rainwater harvested at Ipoh, Perak and Kerteh, Terengganu

4.1.4 Conductivity

Figure 4.10 shows the conductivity data for harvested rainwater at Ipoh, Perah Darul Ridzuan. We can see that the conductivity of the rainwater decrease dramatically as the rainfall increases. The highest conductivity was recorded at 73 uS/cm, while the lowest conductivity was recorded at 25 uS/cm. Figure 4.11 shows the conductivity data for harvested rainwater at Kerteh, Terengganu Darul Iman. The highest conductivity was recorded at 120 uS/cm, while the conductivity value was recorded at 10 uS/cm. The minimum value of a Class I conductivity is 1000 uS/cm. Figure 4.12 shows the conductivity data of both rainfalls from Ipoh, Perak and Kerteh, Terengganu.

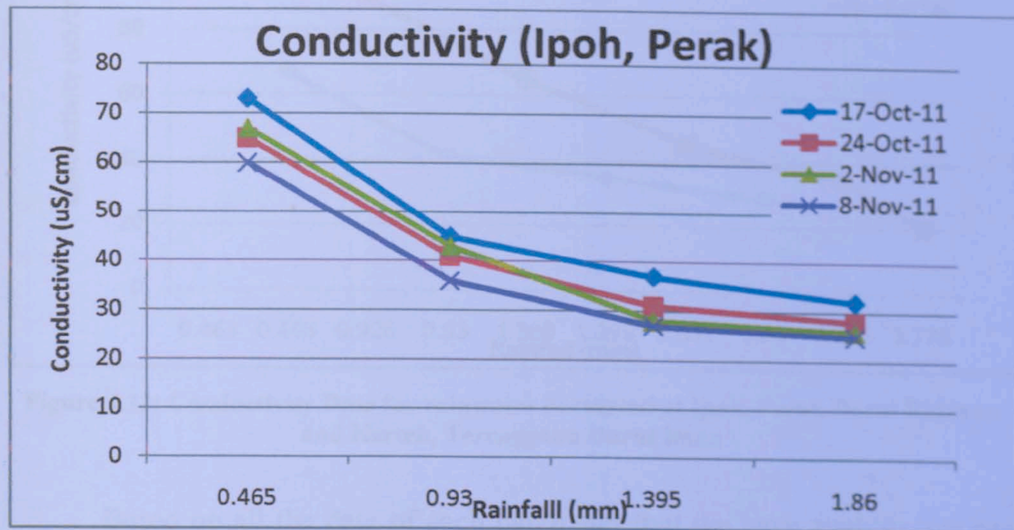

Figure 4.10: Conductivity Data for rainwater harvested at Ipoh, Perak Darul Ridzuan

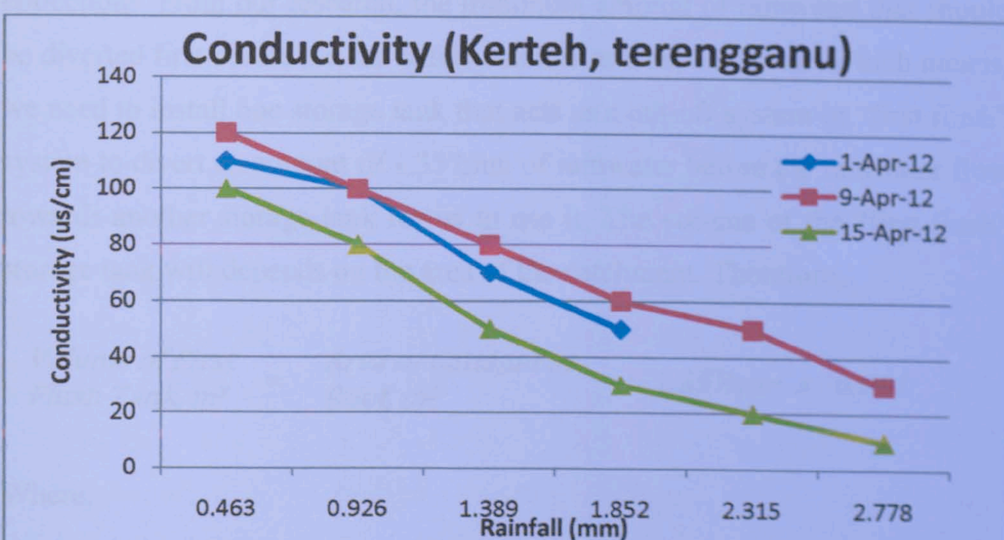

Figure 4.11: Conductivity Data for rainwater harvested at Kerteh, Terengganu Darul Iman

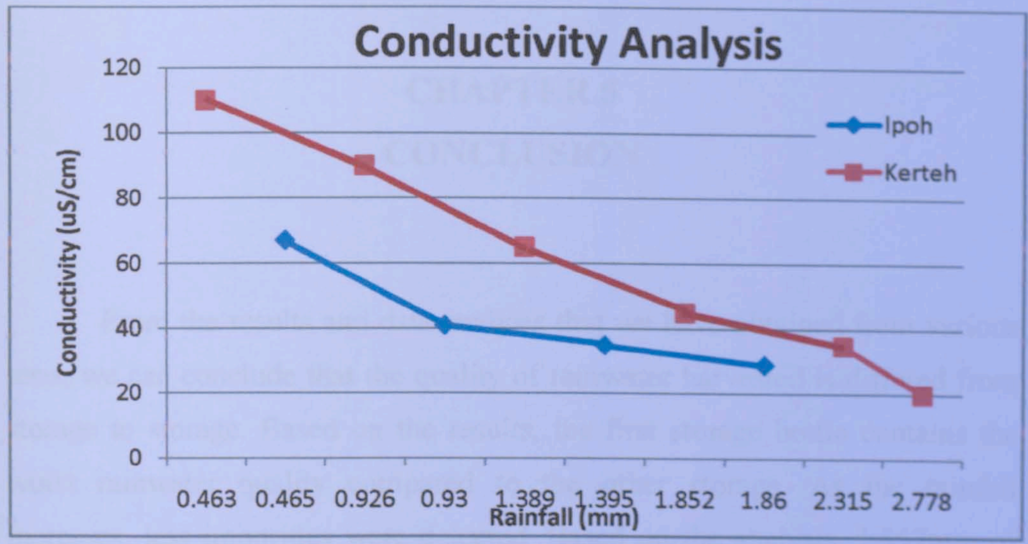

Figure 4.12: Conductivity Data for rainwater harvested at Ipoh, Perak Darul Ridzuan and Kerteh, Terengganu Darul Iman

Based on all the data of each parameter that we have analyse, we can see that the quality of the rainwater is getting better towards the end of the collections. From our research, the minimum amount of rainwater that should be diverted first before we can safely use it is at least 1.357mm. Which means, we need to install one storage tank that acts as a cut-off system or "first flush" system to divert an amount of 1.357mm of rainwater before the rainwater flow towards another storage tank for us to use it. The volume of the "first flush" storage tank will depends on the area of the catchment. Therefore,

$$\textit{Volume of First Flush Tank, } m^3 = \textit{Area of Catchment Roof, } m^2 \times 1.357mm \times 0.001$$

Where,

$$Roof\ Catchment\ Area, m^2 = length, m \times width, m \times \sin\theta\ of\ roof$$

CHAPTER 5
CONCLUSION

From the results and data analysis that we have obtained from various tests, we can conclude that the quality of rainwater harvested is differed from storage to storage. Based on the results, the first storage bottle contains the worst rainwater quality compared to the other storage. As the rainfall increases, less impurities were detected. Based on the analysis, 1.357mm of rainfall is enough to be used as the first flush of the rainwater harvesting model in order for the rainwater to be in a recommended quality. As rain falls and wash up the surface of the roof, it carries all the impurities that have settle before the raining period. If there was no rainfall for a longer period of time, then more debris and particulate matter will settle on the roof, thus affecting the quality of the rainwater. Again, it is important for the engineers to install one storage tank for the purpose of first flush in order to remove unwanted particulate matter which contains in the rainwater. The Difference of environment also contributes towards the quality of the harvested rainwater. Based on the data that we have obtained, we can see that the quality of rainwater at Kerteh, Terengganu is worse than that of Ipoh, Perak. Since Kerteh is known as an industrialized town, therefore we expect it is more polluted than Ipoh, which is an urbanised town. Thus, more debris and particulate matters will either fall together with the rain and or settle on top of the catchment roof.

For recommendation, it is advisable that the elevation of the catchment roof should be less than 40 degree. The lesser the elevation of the catchment roof, the more rainfall we can harvest from the roof. Make sure the roof tiles are properly washed before being installed in the Rainwater Harvesting Model to ensure they are free from debris and particulate matters. For future work, it is advisable that the Rainwater Harvesting Model is installed at other different environment such as near the roadsides where there are lots of debris and particulate matters, or at rural areas which are less polluted. The collection of rainfall should be done at least for 3 rainfall event to obtain more accurate data.

REFERENCES

1) Chang, M., McBroom, M., & Beasley, R. (2004): Roofing as a source of nonpoint water pollution. *Journal of Environmental Management, 73* (4), pp. 307-315.

2) Davis, A., Shokouhian, M., & Ni, S. (2001): Loading estimates of lead, copper, cadmium, and zinc in urban runoff from specific sources. *Chemosphere , 44* (5), pp. 997-1009.

3) Despins, C., Farahbakhsh, K., & Leidl, C. (2009): Assessment of rainwater quality from rainwater harvesting systems in Ontario, Canada. *Journal of Water Supply: Research and Technology — AQUA, 58* (2), pp. 117-135.

4) Efland, C., Eberle, K., & Knight, E (2008, November/December). *Stormwater.* Retrieved March 30, 2010, from Campus Innovation - The UNC Chapel Hill Bell Tower project: *http://www.stormh2o.com/november-december-2008/unc-sustainable-projects-4.aspx*

5) Eletta, O., & Oyeyipo, J. (2008): Rain Water Harvesting: Effect of Age of Roof on Water Quality. *International Journal of Applied Chemistry, 4* (2), pp. 157-162.

6) enHealth Council. (2004): *Guidance on use of rainwater tanks.* Retrieved April 3, 2010, from enHealth Council, National Public Health Partnership: *http://enhealth.nphp.gov.au/council/pubs/pdf/rainwater_tanks.pdf*

7) Farahbakhsh, K., Despins, C., & Leidl, C. (2009): Developing Capacity for Large-Scale Rainwater Harvesting in Canada. *Water Quality Research Journal of Canada , 44* (1), pp. 92-102.

8) Hamdan, S. (2009): A literature based study of stormwater harvesting as a new water resource. *Water Science & Technology — WST*, *60* (5), pp. 1327-1340.

9) Han, M., & Mun, J. (2008): Particle behaviour consideration to maximize the settling capacity of rainwater storage tanks. *Water Science & Technology, 56* (11), pp. 73–79.

10) Harmer Kessel. (2009): *Rainwater Management Systems.* Retrieved March 27, 2010, from Alumasc: *http://www.alumascrainwater.co.uk/pdf/rwsBrochure.pdf*

11) Kahinda, J.-M., Taigbenu, A., & Boroto, J. (2007) : Domestic rainwater harvesting to improve water supply in rural South Africa. *Physics and Chemistry of the Earth, Parts A/B/C, 32* (15-18), pp. 1050-1057.

12) Kirton P.J, P.T. Crisp (1990): The sampling of coke oven emission for Polycyclic Aromatic Hydrocarbons: A critical review, *Fuel 69* (5), pp. 633.

13) Lee C.W, P.M. Lemieux, B.K. Gullett, J.V. Ryan, J.D. Kilgrue (1998): Research on emissions and mitigation of POPs from combustion sources, *Studies in Environmental Science 72* pp. 361.

14) Lye, D. (2002): Health risks associated with consumption of untreated water from household roof catchment systems. *Journal of the American Water Resources Association, 38* (5), pp. 1301-1306.

15) Lye, D. (2009): Rooftop runoff as a source of contamination: A review. *Science of the Total Environment, 407* (21), pp. 5429-5434.

16) Marr L.C, T.W. Kirchstetter, R.A. Harley, A.H. Miguel, S.V. Hering, S.K. Hammond (1999): Characterization of polycyclic aromatic hydrocarbons

in motor vehicle fuels and exhaust emissions, *Environmental Science and Technology 33* (18) pp. 3091-3099.

17) Mastral A.M, M.S. Calle´n, R. Murillo, T. Garcı´a, (1999): Polycyclic Aromatic Hydrocarbons (PAH) and organic matter (OM) relationship in the particulate matter emitted from atmospheric fuidised bed coal combustion (AFBC), *Environmental Science and Technology 33* pp. 3177–3184.

18) Mastral A.M, T. Garcı´a, M.S. Calle´n, J.M. Lo´pez, R. Murillo, M.V. Navarro, (2001): Effects on limestone on polycyclic aromatic hydrocarbon emission during coal atmospheric fludized bed combustion. *Energy and Fuels 15* pp. 1469– 1474.

19) Mastral A.M., M.S. Calle´n, T. Garcı´a(2000): Fluidized Bed Combustion (FBC) of fossil and Nonfossil fuels: a comparative study, *Energy and Fuels 14* pp. 275– 281.

20) Mastral, A.M., Callén, M.S., López, J.M.,Murillo, R., García, T., Navarro, M.V. (2003): Critical review on atmospheric PAH. Assessment of reported data in the Mediterranean basin. *Fuel Processing Technology, 80* (2), pp. 183-193.

21) Meera, V., & Ahammed, M. (2006): Water quality of rooftop rainwater harvesting systems: a review. *Journal of Water Supply: Research and Technology—AQUA , 55* (4), pp. 257-269.

22) Metre, P., & Mahler, B. (2003): The contribution of particles washed from rooftops to contaminant loading to urban streams. *Chemosphere, 52* (10), pp. 1727-1741.

23) Mitchell, V., Deletic, A., Fletcher, T., Hatt, B., & McCarthy, T. (2007): Achieving multiple benefits from stormwater harvesting. *Water Science and Technology, 55* (4), pp. 135-144.

24) Moilleron, R., Gonzalez, A., Chebbo, G., & Thévenot, D. (2002) : Determination of aliphatic hydrocarbons in urban runoff samples from the "Le Marais" experimental catchment in Paris centre. *Water Research* , *36* (5), pp. 1275-1285.

25) Niemczynowicz, J. (1999): Urban hydrology and water management - present and future challenges. *Urban Water* , *1* (1), pp. 1-14.

26) Oamh N.T, L.B. Reutergardh, N.T. Dung (1999): Emission of polycyclic aromatic hydrocarbons and particulate matter from domestic combustion of selected fuels, *Environmental Science and Technology 33* (16) pp. 2703-2709.

27) Polkowska, Z., Gorecki, T., & Namiesnik, J. (2002): Quality of roof runoff waters from an urban region. *Chemosphere* , *49* (10), pp. 1275-1283.

28) Rashid, A., & Darus, Z. (2009): The Conceptual Utilization of Rainwater Harvesting System for Sustainable Campus Development at the Faculty of Science and Technology, University Kebangsaan Malaysia. *3rd WSEAS International Conference on Energy Planning, Energy Saving, Environmental Education*, (pp. 206-211). Tenerife, Spain.

29) Rogge W.F., L.M. Hildemann, M.A. Mazukek, G.R. Cass, B.R.T. Simoneit (1993): Source of fine organic aerosol. 5. Natural gas home appliances, *Environmental Science and Technology 27* (13) pp. 2736.

30) Sazakli, E., Alexopoulos, A., & Leotsinidis, M. (2007): Rainwater harvesting, quality assessment and utilization in Kefalonia Island, Greece. *Water Research, 41* (9), pp. 2039 – 2047.

31) The Schumacher Centre for Technology & Development. (2008): *Rainwater Harvesting - Technical Brief.* Retrieved April 2, 2010, from Practical Action:

http://practicalaction.org/practicalanswers/product_info.php?products_id=376

32) UNEP. (2009). *Rainwater Harvesting: A Lifeline for Human Well-Being.* United Nations Environment Programme. Stockholm Environment Institute.
http://www.unep.org/Themes/Freshwater/PDF/Rainwater_Harvesting_090310b.pdf

33) Wallinder, I., Verbiest, P., He, W., & Leygraf, C. (2000, August): Effects of exposure direction and inclination on the runoff rates of zinc and copper roofs. *Corrosion Science , 42* (8), pp. 1471-1487.

34) Zhu, K., Zhang, L., Hart, W., Liu, M., & Chen, H. (2004): Quality issues in harvested rainwater in arid and semi-arid Loess Plateau of northern China. *Journal of Arid Environments, 57* (4), pp. 487-505.

35) Zimmermann R., H.J. Heger, A. Kettrup(1999): On-line monitoring of traces of aromatic-, phenolic- and chlorinated components in flue gases of industrial scale incinerators and cigarette smoke by direct-inlet laser ionization-mass spectrometry (REMPI-TOFMS), *Journal of Analytical Chemistry 363* (8) (1999) pp. 720-730.

36) Zobrist, J., Müller, S., Ammann, A., Bucheli, T., Mottier, V., Ochs, M., et al. (2000): Quality of roof runoff for groundwater infiltration. *Water Research, 34* (5), pp. 1455-1462.